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The Role of Central Auditory Processing in Attention-Deficit/Hyperactivity Disorder: A Neuropsychological Investigation

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The Role of Central Auditory Processing in Attention-Deficit/Hyperactivity Disorder: A Neuropsychological Investigation

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Dedication

This dissertation is dedicated to my family, including my parents, Frances Rosen Suess and Karl Raymond Suess, who raised me to believe that I could choose my path and to my fiancé, Kris Kwolek, who has helped make the most challenging steps in my path be part of the most special time in my life.

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The Role of Central Auditory Processing in Attention-Deficit/Hyperactivity Disorder: A Neuropsychological Investigation

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Central Auditory Processing Disorder (CAPD) is defined as a modality-specific perceptual dysfunction that is not due to peripheral hearing impairment (McFarland & Candace, 1995). It may include limitations in the ongoing transmission, analysis, transformation, elaboration, storage, retrieval and use of auditory stimuli. CAPD has also been reported to be associated with difficulties in memory, reading, spelling, language, and attention. The broad conceptualization of CAPD has contributed to difficulty in the diagnosis and treatment of children who present with auditory processing impairment. A major concern related to the lack of specificity in the definition of CAPD is the inclusion of attention. The clinical overlap in CAPD and ADHD has led to research questions regarding the validity of CAPD as a distinct disorder.

Participants were 30 children aged eight to 14 re-recruited from a larger study investigating social competence in ADHD. They were asked to volunteer to complete additional measures of attention and auditory processing. Prior to participating they had completed the Behavioral Assessment System for Children- Parent Rating Scale (BASC-PRS) and the SIDAC. The BASC was used as measure of externalizing behavior and the SIDAC was used to classify participants into subtypes of ADHD. Participants completed the SCAN (Keith, 1995) as a measure of auditory processing and the Tests of Variables of Attention- Auditory (T.O.V.A.-A.) as a measure of attention. Participants were placed into groups based on their subtype of ADHD. There were two groups including ADHD/PI and a collapsed group including ADHD/combined and ADHD/HI. Discriminant function analysis was used to determine the accuracy of classification into subtypes using combinations of the predictor variables.

Results of the analyses indicated that externalizing behavior was the most robust predictor variable, with an accuracy rate of 80 percent. Including auditory processing and auditory attention did not improve the classification rate. When used alone as a predictor variable, auditory processing was not found to not be effective in classifying participants. Results have research and clinical implications. Sensitivity and specificity issues related to the measures used are discussed. Recommendations for future research are offered.

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Chapter 1: Introduction

The ability of children to process auditory stimuli in such a way that allows them to construct an accurate meaning and understanding of information is necessary in school, home, and social contexts. For some children, processing auditory stimuli is an area of marked impairment, which often results in a lower level of functioning in these areas. For instance, children who demonstrate impairment in their ability to process auditory information may have academic difficulties as they struggle to understand class presentations that are presented orally. At home, children with auditory processing impairment may find themselves needing directions repeated more times than typical for children their age. Such difficulty is often met with frustration on the part of the caregiver and therefore threatens important familial relationships. For children with this impairment, social functioning may also be affected. Children challenged by auditory processing deficits often have a difficult time engaging in spontaneous social interactions necessary to build healthy friendships.

Children who are identified as having difficulties similar to those described above are sometimes diagnosed with Central Auditory Processing Disorder (CAPD). Since its introduction approximately 40 years ago, auditory processing impairment has remained somewhat elusive in terms of its biological, neuropsychological, and behavioral correlates. Research to date has focused primarily on efforts to provide a foundation for auditory processing impairment having biological underpinnings. At the present time, CAPD is defined as a disorder specifically of the central auditory processing system (Musiek & Baran, 1987).

CAPD is a relatively new diagnosis that is currently recognized by the American Speech-Language-Hearing Association (1992). Although attempts have been made to specify diagnostic criteria for CAPD, diagnosis continues to be an area of concern. In fact, the disorder is not recognized in the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; American Psychiatric Association, 2000).

CAPD is difficult to diagnose due to an etiological perspective that defines CAPD as a perceptual disorder that is modality specific. Based on this perspective, auditory processing should not be accounted for by problems in other areas of functioning; such attention, memory, or language. However, CAPD is described as a disorder that often co-occurs with problems in these areas.

Of recent controversy has been the relationship between CAPD and Attention-Deficit/Hyperactivity Disorder (ADHD). The lack of understanding about how these disorders are related also contributes to diagnostic problems. Poorly developed listening skills are common in children with ADHD, and "difficulty listening" is a symptom used to diagnose ADHD. Theoretically, difficulty listening in children with ADHD should be caused by attentional impairment and difficulty listening in children with CAPD should be caused by deficits in auditory processing. However, overlap between CAPD and ADHD is common. Studies that have investigated the co-occurrence of ADHD in CAPD have come to mixed conclusions regarding the nature of attentional difficulties in each disorder. An overarching theme regarding attentional problems in each disorder is whether these problems are specific to one mode of attention, or whether they occur across modes. Specifically, questions have been raised whether attentional disorders affect auditory and visual systems or one of these systems exclusively.

Just as understanding the role of ADHD in children with CAPD is imperative; understanding the role of CAPD in ADHD is of great clinical relevance. In contrast to CAPD, ADHD has been studied extensively in regards to emotional, behavioral, and interpersonal functioning of children with ADHD. Understanding and intervening in respect to these areas is integral to preventing negative outcomes in children with ADHD as they enter adolescence and adulthood. Children with ADHD are at risk for both internalizing and externalizing disorders in adolescence, as well as maladaptive coping strategies, such as substance abuse. Adults with ADHD who have a history of conduct problems and/or maladaptive interpersonal relationships are at risk for the development for certain personality disorders, especially with the presence of severe conduct problems. Thus being able to identify patterns and subtypes within ADHD will allow for interventions to be tailored more specifically to children.

Neuropsychological studies of children with ADHD have made great strides in the past decades in working to identify patterns of neuropsychological functioning in ADHD. In time, research will continue to move further in linking social and emotional correlates to the multiple expressions of ADHD that are the focus of current research. Despite the growth in this area, there are no conclusive patterns of neuropsychological functioning in children with ADHD. Examples of areas that have been of focus of neuropsychological include executive functioning, which involves a variety of more specific areas related to planning; behavioral inhibition; and inattention.

CAPD as it occurs in ADHD has not been well investigated in the field of ADHD. Studies to date present a variety of weaknesses that result in difficulty with interpretation. Studies of CAPD in ADHD prior to the present study did not look at specific subtypes and used a limited battery of measures. Thus, the debate regarding the role of central auditory processing in ADHD was an area in need of future research. One major goal of this dissertation was to address some of the gaps in previous research. Namely, subtypes of ADHD were differentiated in order to learn more about the differences between these groups. Additionally, the battery used for this dissertation expanded upon batteries used in former studies.

A second goal of this dissertation was to look more specifically at neuropsychological patterns of performance of subtypes of ADHD. Attention was applied as an area of functioning that has been established in the literature as impaired in children with ADHD. Behavioral problems were also addressed as characteristically being more representative of children with ADHD/ predominantly hyperactive and ADHD combined subtypes. Auditory processing was conceptualized as an area of neuropsychological functioning that was not clearly understood in its relationship to ADHD.

The ensuing literature review will first summarize the literature on central auditory processing and CAPD and then will focus on attentional deficits as they occur in CAPD. Next, biological underpinnings of central auditory processing will be addressed. The review will then move to focus on ADHD, followed by a summary on literature that has addressed central auditory processing deficits in ADHD.

Chapter 2: Literature Review

CENTRAL AUDITORY PROCESSING DISORDER

Central auditory processing was first conceptualized as an area of neuropsychological functioning approximately 30 to 40 years ago (Musiek & Baran, 1987). Soon thereafter research began to address Central Auditory Processing Disorder (CAPD), which is used to describe impairment in central auditory processing. Central auditory processing may also be referred to as "central hearing," as it describes hearing centered in the brain rather than hearing centered in the ears. CAPD is not recognized as a psychological disorder; however the field of speech and hearing sciences does recognize and diagnose CAPD.

The American Speech-Language-Hearing Association (1992) offers a broad definition of CAPD as deficits in the processing of audible signals that cannot be attributed to impaired peripheral hearing sensitivity or intellectual impairment. Specifically, CAPD is defined as "limitations in the ongoing transmission, analysis, organization, transformation, elaboration, storage, retrieval, and use of information contained in audible signals" (p. 41). The report presented by the American Speech-Language-Hearing Association includes other areas of impairment that may be observed in children with CAPD, which include attention, memory, reading, spelling, and written language. The broad definition of CAPD leads to difficulties in specifying the nature of the impairment.

Although the aforementioned definition of CAPD includes a broad range of neurocognitive correlates, some researchers describe CAPD as a modality-specific perceptual dysfunction (McFarland & Cacace, 1995). It is assumed that impairment in auditory perception is the underlying cause of language-based learning disorders (Katz & Wilde, 1985). However, CAPD has been associated with specific reading disorders and developmental dysphasia. Thus, it has also been theorized that processing deficits more often are demonstrated in multiple sensory modalities (McFarland & Cacace, 1995).

The conceptualization of CAPD as a modality-specific perceptual deficit involves the assumption that central auditory processing is the primary area of impairment. Thus, individuals with CAPD should demonstrate difficulty in tasks requiring the processing of acoustic information. Based on this assumption, individuals with CAPD should not demonstrate difficulties when similar types of information are processed in other sensory modalities, such as visually (McFarland & Cacace, 1995).

CAPD is not diagnosed in the field of psychology, and current diagnostic criteria in the field of speech and hearing sciences are tenuous given the assumption that CAPD is modality-specific, but, as previously discussed, may occur with a host of other cognitive impairments (American-Speech-Language-Hearing Association, 1992). McFarland and Cacace (1995) posit that an appropriate diagnosis of CAPD should involve testing that is able to differentiate cases of auditory perceptual deficits from those with non-perceptual deficits. Chermak, Traynham, Seikel, and Musiek (1998) provide a report of current central auditory assessment practices of audiologists in the United States. The acoustic reflex, auditory brainstem response, and SCAN (Keith, 1997) were reported as the most common test procedures. However, Chermak et al. (1998) note that 41% had received only minimal training in the assessment of CAPD.

From a developmental perspective, central auditory processing has been theorized to be an area of neurocognitive functioning that unfolds in turn with neurolinguistic maturation. Neville (1993) purports that there are linguistic capacities which develop in timed stages in children in accordance with neuronal growth. For instance, lexical growth may precede grammatical growth. In order for grammatical growth to begin, there must be lexical accumulation. Thus, specific language impairment may occur if there are disruptions at critical development times (Neville, 1993). Other theories implicate auditory processing as the basic deficit that underlies other language impairments. In addition, impairment is not specific to language, and may be demonstrated also in memory and motor skills (Stark and Tallal, 1988).

CONTROVERSY SURROUNDING CAPD

Central auditory processing is a controversial area of neuropsychological functioning. Definitional problems have led to a lack of clarity regarding the diagnosis of Central Auditory Processing Disorder (CAPD). Also, the overlap of symptoms of CAPD with symptoms of ADHD, especially ADHD predominantly inattentive subtype, has resulted in comorbidity of the disorders that is not well understood. The relationship between ADHD and CAPD will be discussed in depth in a later section.

The definition of CAPD encompasses a broad array of neuropsychological correlates despite the fact that the disorder is defined as modality-specific and perceptual in nature. Therefore, diagnosis of CAPD becomes difficult due to definitional problems. The definition offered by the American-Speech-Language and Hearing Association (1992) includes impairment of attention, memory, and academic functioning as likely correlates. However, the specific pattern of cognitive performance in CAPD has not been well documented. Additionally, CAPD is also defined as a perceptual disorder; however, correlates of CAPD are not necessarily perceptual in nature, which also Cacace and McFarland (1998) state that, "…whether or not a child is diagnosed with ADHD or CAPD depends often on whether the child is being diagnosed by an audiologist or a psychologist" (p. 25). Although this statement may be considered extreme, it does indicate that there is a significant overlap between ADHD and CAPD.

Studies to date have not provided consistent information regarding the nature of the relationship between CAPD and ADHD. More specifically, studies have not provided consistent information regarding whether CAPD represents a distinct disorder or instead if central auditory processing is a neuropsychological correlate of ADHD. Additionally, studies have not addressed whether it is perceptual difficulties that separate the disorders. Although a link between etiologies of the disorders remains unclear, intervention has established the methylphenidate is useful in the treatment of both disorders (Keith & Engineer, 1991). This raises the question regarding neurological similarities between the disorders.

A Biological Basis For CAPD

The biological basis for CAPD involves structures of the brain that research has demonstrated are integral to the processing of auditory information. Subcortical and cortical areas of the brain have also been implicated in research investigating auditory pathways of the brain. In addition, the biological basis for CAPD involves the function of processing auditory stimuli through the brain's auditory system. Thus, the complexity of central auditory processing can best be conceptualized as an integration of structural components and functional aspects of the auditory processing system, which underlie what has been termed central auditory processing.

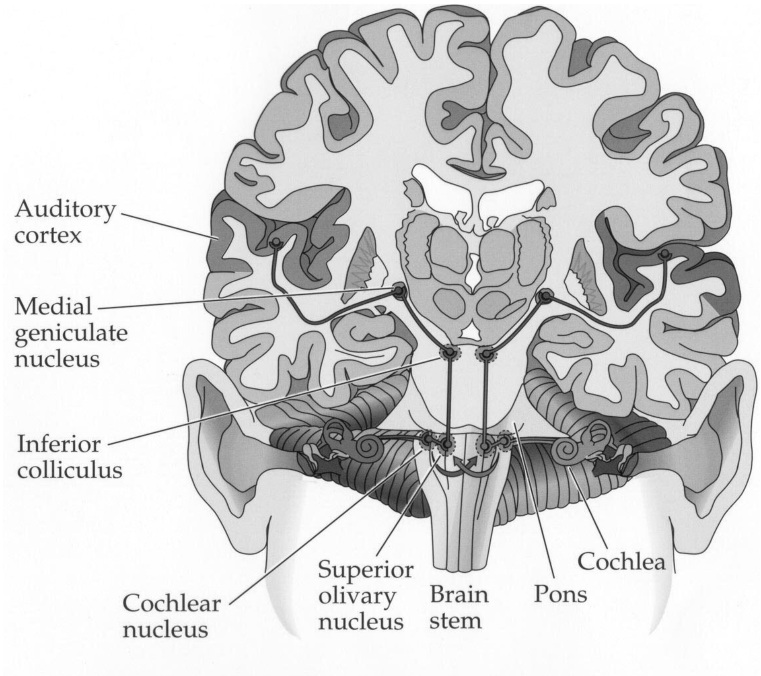

Illustration 1: Auditory Pathways of the Brain.

Central auditory regions compose what is known as the central auditory nervous system (CANS) (Musiek & Lee, 1998). Although the CANS remains an area in need of future research, animal research has provided a basic understanding of the central auditory nervous system. In addition, research with humans who suffered lesions resulting central auditory processing difficulties provides implications for the functioning of this system

According to Musiek and Lee (1998), the internal capsule is an important subcortical structure involved in the auditory system. The internal capsule contains afferent auditory fibers that are directed to cortical regions. Musiek (1986) states that the majority of fibers in the internal capsule are anterior. However, the internal capsule contains some posterior fibers. The posterior internal capsule is susceptible to disconnection from the cortex due to a high density of auditory fibers. Thus, central deafness could occur from a subcortical lesion due to the inability for information to be transmitted through the fibers in the internal capsule.

The insula is a cortical structure that plays an important role in the CANS. Millin et al. (1995) conducted an fMRI study that found that the insula became activated during certain acoustic tasks. Also, the insula sits directly adjacently to Heschl's gyrus. If further research replicates the findings of Millin et. Al (1995), then it may be posited that damage to the insula may result in central deafness.

Based on the results of a case study of four patients with central deafness, Musiek and Lee (1998) hypothesize that other parts of the brain besides Heschl's gyrus may result in central auditory impairment if damaged. Specifically, it is speculated that inferior segments of the parietal lobe, including its inferior segment immediately superior to Heschl's gyrus, the supramarginal gyrus, and possibly small segments of the anterior angular gyrus and inferior frontal lobe are acoustically sensitive areas (Musiek, 1986). In addition, due to the proximity of these structures to Heschl's gyrus it is unlikely that damage to these areas would leave Heschl's gyrus untouched.

Kraus, McGee, and Koch (1997) contend that there are three areas of central auditory representation which are relevant to the biological basis of CAPD. According to Kraus et al. (1997), speech is a complex acoustic signal that changes in the frequency, amplitude, and time domains. In order to make sense of speech, the pattern of each individual sound, or signal, must be meaningful to the individual. Thus, it is ultimately the pattern of sounds that result in meaningful speech. Kraus et al. (1997) refer to central sensory representation of speech sounds as occurring independently of peripheral sensory encoding and independent of conscious perception.

Voice-onset-time (VOT) describes how speech sounds are represented in central auditory pathways. Koch et al. (1997) demonstrated the representation of VOT in cortical potentials recorded from human subjects whereas other research has demonstrated the representation of VOT in animals (Steinschneider et al. 1994; Eggermont, 1995; McGee et al., 1996).

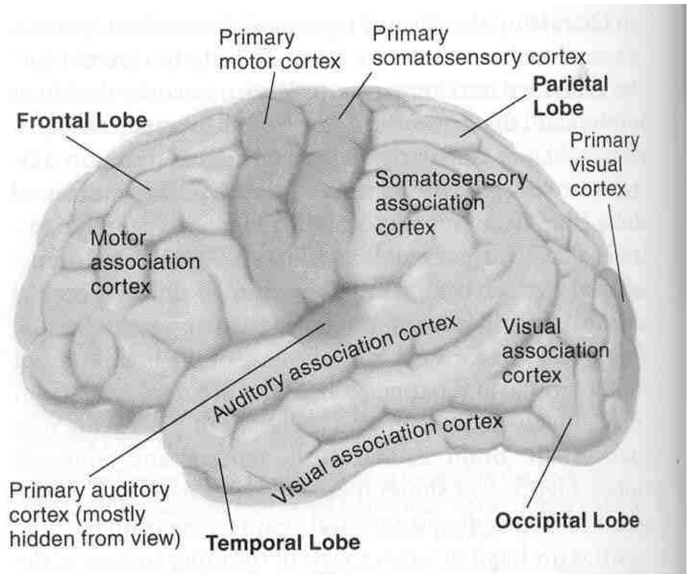

Illustration 2: Auditory Association Areas.

Research has also demonstrated that different acoustic parameters may be encoded distinctively through the auditory pathway (Kraus et al., 1997). This line of research has contributed to the understanding of cortical contributions to auditory processing. Koch, Tremblay, Dunn, and Dinces (1997) provide evidence that certain sounds may be more vulnerable to disruption. For example, the perception of certain consonants may be disrupted in individuals with auditory cortex lesions. Precisely timed transient elements may be well represented centrally.

Kraus, McGee, Carrell, and King (1994) hypothesize that certain contrast pairs (/da/-/ga/) occur at areas other than the auditory thalamus, whereas contrast pairs including /ba/-/wa/ occur at the thalamus. Thus, the auditory processing pathway shows specialization of processing that involves certain discriminations to be processed at the cortical level. In addition, Kraus et al. (1997) suggests that that left-side speech specialization is evident for the processing of basic speech sounds.

Kraus, McGee, Carrell, and Zecker (1996) explored the relationship between a mismatched response to behavioral discrimination of selected speech sounds in normal and learning-disabled children. The results indicated that for approximately 30 percent of the children with learning disabilities included in the study, speech-sound perception may arise from faulty representation in central auditory centers at an automatic level.

Binder et al. (1994) offers a summary of the pathway through which auditory stimuli are processed. Binder, Rao, Hammeke, and Frost (1994) concur with Kraus (1997) in that the auditory processing system is hierarchal in nature; specifically, the superior temporal lobes are involved in the decoding the acoustic signals of speech whereas the left frontal lobes are primarily involved in semantic operations. However, Binder et al. (1997) contends that both hemispheres are involved in auditory processing, rather than solely the left hemisphere. Specifically, interconnectivity between the right and left hemispheres is necessary for higher-level cognitive activities. In general, Binder et al. (1997) suggests that as language activities become more complex, more regions of the brain are involved.

According to Kraus et al. (1997), speech perception abilities can be modified with training and that modification may generalize to other listening contexts. Thus, it is suggested that there is an underlying plasticity in the central auditory processing system. The specific neurophysiologic mechanisms that lead to speech-sound perceptual learning and plasticity are not known at the present time. However, based on research conducted by Kraus (1997), auditory processing impairment may be responsive to intervention.

ATTENTION-DEFICIT IN CAPD

The tendency for children with CAPD to also meet diagnostic criteria for ADHD highlights the clinical question of determining which disorder is to be considered primary, or whether the disorders occur simultaneously in this group of children. According to Chermak and Musiek (1992), children with CAPD are often characterized as having difficulties in the areas of hyperactivity and inattentiveness. There is a dearth of literature that has studied attentional deficits in children with CAPD. However, there are a number of studies that have investigated auditory processing impairment in children with ADHD, which will be discussed in a later section.

At the present time, investigation of auditory versus other modes of attention has been the primary way to conceptualize the underlying cause of attentional problems in CAPD versus ADHD. Bedi, Halperin, and Sharma (1994) investigated the CAPD diagnosis in children with ADHD who were described as having difficulty listening. Specifically, they studied whether these children's inattentiveness is more pronounced with auditory stimuli than with stimuli presented in other modalities.

Results indicated that inattentiveness could be modality specific. It was found that children with ADHD who demonstrated distractibility with visual stimuli also demonstrated impairment on continuous performance test (CPT) measuring attention and were more likely to be rated as ADHD on teacher rating forms. In contrast, children with ADHD who demonstrated difficulties with auditory distractibility did not demonstrate impairment on the CPT or teacher ratings, but did demonstrate reading impairment (Bedi et al., 1994). These findings suggest that visual and auditory attention may represent different manifestations of impairment of the attentional system.

According to Jonkman, Kemner, Verbaten, and Koelega (1997), abnormal patterns of electrical activity occur in children with ADHD when processing certain modes of information. In this study, Jonkman et al. (1997) sought to determine if abnormal auditory selective attention is reflected in the processing negativity of the event-related potential. They also investigated if the processing negativity was related to frontal lobe functioning. The authors found abnormalities demonstrated by less modulation of auditory cortical activity in children with ADHD, but did not find a relationship to the frontal lobe (Jonkman et al., 1997).

Cacace and McFarland (1998) suggest that ADHD is a cross-modal disorder that involves attentional impairment across domains. Although there are alternative theories regarding the conceptualization of ADHD, the multi-modal conceptualization of attentional difficulties in ADHD implicates how CAPD and ADHD may be differentiated based on performance on measures of attention. However, ADHD is usually diagnosed using visual attention tasks (Cacace and McFarland, 1998). This may due to the fact that most visual attention tests were developed prior to auditory attention tests, rather than due to visual attention being notably more impaired in ADHD than auditory attention.

Riccio, Cohen, Hynd, and Keith (1996) studied the use of a test of auditory attention in distinguishing CAPD with and without ADHD. Thirty children diagnosed with CAPD were divided into two groups based on whether or not they had coexisting ADHD. Results indicated that the measure of auditory attention was not effective in differentiating the groups (Riccio et al., 1996).

Because both groups entered the study having already been diagnosed with CAPD, it is not surprising that both groups demonstrated similarly impaired performance on a measure of central auditory processing. In order to conclude whether or not a measure of auditory attention is useful in distinguishing ADHD from CAPD, a group of ADHD only children would have been useful. In addition, including a measure of visual attention would have provided relevant information.

ATTENTION/DEFICIT HYPERACTIVITY DISORDER (ADHD)

Teeter and Semrud-Clikeman (1994) provide a description of ADHD that conceptualizes ADHD as a disorder involving a disturbance in attention span, self-regulation, and impulsivity (p. 126). As a result, children with ADHD may display symptoms such as poor attention; impulsive behavior and motoric overactivity. In addition, children with ADHD may have difficulty anticipating the consequences of their behavior. Poor planning and judgment are also thought to contribute to overall behavioral problems.

ADHD has been a prominent area of research for the past 45 years. Since then, ADHD has been termed minimal brain damage; hyperkinetic syndrome; hyperkinetic reaction in childhood; attention deficit disorder with and without hyperactivity; and attention deficit disorder predominantly hyperactive and predominantly inattentive, and combined (Teeter and Semrud-Clikeman, 1994, p. 123). According the DSM-IV-TR (American Psychiatric Association, 2000), the prevalence of ADHD among school-age children has been estimated to be between three and seven percent.

EXTERNALIZING BEHAVIOR IN ADHD

Research indicates that ADHD is usually first recognized by parents when children are toddlers and they are more active than typical for their age (American Psychiatric Association, 2000). Overactivity usually develops concurrently with locomotor skills. For many children with ADHD, it is initially diagnosed during early school years when behavioral difficulties occur. However, for children with ADHD predominantly inattentive type, diagnosis may be delayed due to the absence of behavioral problems.

Symptoms of ADHD usually stabilize during adolescence. Specifically, hyperactive symptoms typically subside and inattentive symptoms become prominent.

Some adults may see attenuation of both hyperactive and inattentive symptoms. ADHD is difficult to diagnose in children younger than five years of age, according to the DSM-IV-TR (American Psychiatric Association, 2000). Adults who are first diagnosed as adults must have a history of childhood symptoms.

There also appears to be gender differences in ADHD (American Psychiatric Association, 2000). ADHD occurs more frequently in males than females with ratios ranging from 2:1 to 9:1; depending on which subtype is being investigated, as females are more likely to have the predominantly inattentive subtype. The disorder has been exhibited in a variety of Western cultures and prevalence appears to be increasing following the recognition of the inattentive subtype.

The Diagnostic and Statistical Manual for Psychiatric Disorder-IV-Text Revision (DSM IV-TR) (American Psychiatric Association, 2000) offers diagnostic information for ADHD. The nosologic systems for diagnosing ADHD have evolved over the past several decades; however, there remains a theme of the existence of two basic symptom clusters. One cluster involves symptoms of hyperactivity and impulsivity and the other cluster involves symptoms of inattention. The DSM-IV-TR (American Psychiatric Association, 2000) recognizes three major types of ADHD. These include predominantly inattentive (ADHD/PI), predominantly hyperactive/impulsive (ADHD/HI), and combined subtype (ADHD/C).

In concordance with the neuropsychological correlates of ADHD, which will be discussed in the next section, are a variety of other areas of functioning that may be impacted in children with ADHD. Academic difficulties and socialization problems may be present early in development. As children with ADHD develop, they may begin to show symptoms of internalizing and/or externalizing disorders. In addition, their functioning in the family may be and area of concern.

Research has indicated that children with ADHD exhibit more academic difficulties when compared to their same-age peers. Generally, research supports greater academic difficulties among children with ADHD/PI than among children with ADHD/HI. However, studies that have reported this finding have been based largely on teacher reports rather than measures of academic functioning.

Edelbrock (1984) reports that whereas 16.7% of children with ADHD/HI repeated a grade, 71.4% of children diagnosed with ADHD/PI had been held back. Carlson, Lahey, and Neeper (1986) did not find differences in discrepancies between IQ and achievement scores between the subtypes. However, teachers rated children with ADHD/PI as having more learning problems than children with ADHD/HI. Weiler et al. (2002) note that children with ADHD/PI type are often described by teachers as sluggish and have academic difficulties. Specific neuropsychological correlates related to learning will be discussed in a later section.

Another major area of difficulty for children with ADHD is social competence. Approximately 50% to 75% of children with ADHD are believed to suffer from social impairment. Hupp & Reitman (1999) contend that emotional regulation deficiencies lead to social incompetence on the part of children with ADHD. Alternatively, Voeller (1994) posits that difficulties with social competence are due to performance deficits rather than acquisition deficits. Thus, children with ADHD may be likely to understand social skills, but have difficulty performing such skills. They are likely to behave impulsively when interacting with peers and have difficulty inhibiting socially inappropriate behaviors (Frederick and Olmi, 1994).

There may also be differences in the reactions of peers to social deficiencies between the subtypes of ADHD. Research indicates that children with ADHD/PI are more likely to be rejected by peers through being ignored whereas children with

ADHD/HI are more likely to be actively rejected (Lahey & Carlson, 1991). In addition, children with ADHD/PI may be perceived as socially withdrawn by their peers.

Children with ADHD are more prone to develop a myriad of difficulties as they mature into adolescence. Such difficulties can present in the form of internalizing and externalizing disorders and likely stem from maladaptive relational patterns that developed over time. Research that has investigated internalizing in children with ADHD has provided inconsistent results. Early research (Lahey & Carlson, 1992) indicated that children with ADHD/PI demonstrated higher levels of internalizing symptoms than children with ADHD/HI.

More recently, Power, Costigan, Eiraldi, and Leff (2004) investigated whether the level of internalizing symptoms differed between inattentive and combined subtypes of ADHD. Power et al. (2004) studied a sample of 729 clinic-referred children. They used a structured interview and checklists to measure internalizing symptoms. Externalizing behavior was used as a covariate. Results indicated that children with both subtypes demonstrated similar levels of anxiety and depression. Differences between groups in parent reports of internalizing symptoms were accounted for by parent reports of externalizing symptoms (Power et al., 2004).

These results indicate that children with predominantly inattentive ADHD do have higher levels of anxiety and depression than children with ADHD combined subtype. Power et al. (2004) put forth the idea that both the combined group and the inattentive group may have what they refer to as, “sluggish cognitive tempo” (SCT). Further research is necessary to determine if high levels of SCT lead to higher levels of anxiety and depression.

Fischer, Barkley, Smallish, and Fletcher (2002) looked more specifically at the outcomes of children with ADHD predominantly hyperactive in regards to psychopathology present in young adulthood. The study found that predominantly hyperactive children were also apt to experience secondary psychological disorders. This study compared psychological adjustment of 147 hyperactive children at follow-up, placing the children at a mean age of 21 years, to a non-clinical control sample of 71 young adults of similar ages.

Results indicate that children with ADHD/HI are at significant risk for at least one disorder, excluding substance abuse, in adulthood. Major depression and several personality disorders were most frequent (Fischer et al., 2002). Antisocial Personality Disorder (ASPD) was overrepresented in the sample; however, severity of conduct problems in adolescence mediated these results. This was found even when severity of hyperactive symptoms of ADHD in childhood was controlled for. Histrionic and Passive-Aggressive Personality Disorders were also overrepresented in the sample, but were not found to be a function of conduct problems. Lastly, Borderline Personality Disorder (BPD) was overrepresented in the sample. Results indicated that risk for BPD in ADHD hyperactive children is increased by the severity of conduct problems in adolescence.

In summary, the results suggest that hyperactivity in adulthood does not increase risk for BPD or ASPD in adulthood, rather severe Conduct Disorder increases risk for these disorders. However, hyperactivity does appear to increase the risk for Histrionic and Passive-Aggressive Personality Disorders (Fischer et al., 2002). These findings indicate that severe conduct problems are a more effective predictor of future psychopathology in hyperactive children in the case of most disorders.

Difficulty functioning well in their family may be an area of concern for children and adolescents with ADHD. Children with ADHD may experience more conflict with their parents than typical for children, according to Edwards, Barkley, Laneri, and Fletcher (2001). Based on the transactional model presented by Edwards et al. (2001), conflict of this nature may result into hostility between children and their parents, which ultimately leads to feelings of rejection similar to the rejection children with ADHD experience with peers.

A BIOLOGICAL BASIS FOR ADHD

Neuropsychological studies have attempted to implicate areas of the brain that are involved in the development of ADHD. According to Teeter & Semrud-Clikeman (1997), there have been approximately 11 neuroanatomical studies put forth in regards to the etiology of ADHD. Currently, biological underpinnings that involve the right frontal lobe and the corpus callosum are most supported by research in this area. In addition to studies that have attempted to identify structure of the brain that may lead to attentional problems, neuropsychological studies have addressed functional aspects that are related to ADHD. Also, an area of research has focused on specific neuropsychological impairment in children with ADHD.

Consistent support has been found for the involvement of the corpus callosum, specifically the posterior portion referred to as the splenial (Hynd, Semrud-Clikeman, Lorys et al., 1991). The results of this exploratory study indicate that children with ADHD may have a smaller corpus callosum when compared to normal children. Prior research (Hynd, Semrud-Clikeman, Lorys, Novey, & Etiopulos, 1990; Chelune, Ferguson, Koon, & Dickey, 1986; Voeller & Heilman, 1988; Schaughency & Hynd, 1989) indicated the involvement of the right frontal lobe through a MRI study. The relationship between the corpus callosum to the right frontal lobe supports hypotheses that both areas play a critical role in the development of ADHD.

Teeter and Semrud-Clikeman (1994) offer the conceptualization of ADHD as a disorder of motor inhibition in the case of ADHD/HI or a disorder of interference sensitivity in the case of ADHD predominantly inattentive type (p. 121). However, it is noted that although the attentional system is multifaceted, disruption in one area will likely affect other areas. Interference sensitivity refers to the difficulty ADHD children have filtering out extraneous stimuli.

Another neuropsychological aspect of ADHD involves the differences between basic and higher mental control. Benson (1991) summarizes higher mental control as the ability to monitor and regulate various networks of complex mental operations, such as motor activity and abstract thinking. Because such operations are spread across both hemispheres, there may be competition between hemispheres for attention (Teeter & Semrud-Clikeman, 1997, p. 121).

NEUROPSYCHOLOGICAL FUNCTIONING IN ADHD

Performance on neuropsychological measures has been shown to be different between children with ADHD and normal children and between subtypes of ADHD. Both groups generally demonstrate areas of impairment; however there does appear to be evidence of different patterns of impairment between subtypes of ADHD. Research in this vein has been used to support whether ADHD/PI is a separate, distinct disorder; or whether the subtypes of ADHD fall along a continuum of attentional impairment. Neuropsychological domains that have been investigated include executive functioning, attention, processing speed, and working memory. Central auditory processing will be discussed specifically in the next section.

Chelune, Ferguson, Koon, and Dickey (1986) found that children with ADHD demonstrated impairment on the Wisconsin Card Sort Test (WCST), which is designed to measure executive functioning. Attempts to replicate these results have not found differences between ADHD and controls on performance on the WCST (Fischer, Barkley, Edelbrock, & Smallish, 1990; Loge, Staton, & Beatty, 1990). Neither study differentiated between subtypes of ADHD and neither study controlled for comorbid disorders.

Studies that have used a Stroop test, also designed to measure executive functioning, have been inconsistent (Lahey and Carlson, 1991). Teeter and Semrud-Clikeman (1994) suggest that failure to replicate impairment on the WCST may be due to studies not separating subtypes or controlling for comorbid disorders (p. 126). This may also account for inconsistent results in studies using the Stroop test.

Multiple aspects of attention are described by Teeter and Semrud-Clikeman (1994). Vigilance is described as sustained attention, which refers to the "…ability to maintain a behavioral response for a continuous or repetitive activity" (Teeter & Semrud-Clikeman, 1994) (p. 120). Selective attention is described as, "…a complex behavior that requires the maintenance of a response involving activation of another response." Lastly, Teeter and Semrud-Clikeman (p. 121) contend that the complex forms of attention are alternating attention and divided attention, which involve the ability to split attention between multiple mental operations. Selective attention is noted be impaired in children with ADHD predominantly inattentive.

An area of neuropsychological functioning that has been investigated in children with both subtypes of ADHD is processing speed. Weiler, Bernstein, Bellinger, & Waber (2002) found that children with ADHD/PI performed poorly compared to controls on measures of processing speed; however, this difference was evident only during visual search tasks and did not generalize to auditory processing or motor learning. Alternatively, children with ADHD/HI have been shown to have longer reaction times and difficulty completing finger sequential tasks.

Hynd, Nieves, Conner, and Stone (1989) examined the speed and efficiency of information neurocognitive processing of 43 children with ADHD/HI, 22 children with

ADHD/PI, and 16 controls. Children with ADHD/PI performed significantly worse than controls on letter-string matches. Results also indicated that children with ADHD/HI did not differ from either group on measures of speed or variability of response (Hynd et al., 1989).

According to Cutting, Koth, Mahone, and Denckla (2003), learning in the verbal domain requires working memory. Thus, the California Verbal Learning Task (CVLT) is believed to tap into working memory. Cutting et al. (2003) examined verbal learning in children with ADHD without reading disorders. The group of children with ADHD included 10 children who were classified ADHD/PI, 3 children who were classified as ADHD/HI, and 5 children who were classified as combined type. Results indicated that children with ADHD initially learned the same number of words as controls, but showed impairment in their ability to recall the words after a delay. In addition, analyses of semantic clustering indicated that girls utilized semantic clustering more frequently than boys and outperformed boys in overall performance (Cutting et al., 2003).

CENTRAL AUDITORY PROCESSING IN INDIVIDUALS WITH ADHD

CAPD is recognized in the field of speech and hearing sciences as a disorder that is distinct from ADHD. However, as previously discussed, the DSM-IV-TR (American Psychiatric Association, 2000) does not recognize CAPD as a psychiatric disorder. Rather, the general consensus in the literature has been that CAPD and ADHD are not separate disorders and instead CAPD represents a clinical presentation of ADHD rather than a distinct disorder. However, although consistent in their findings, studies that have addressed the comorbidity between ADHD and CAPD are sparse.

A number of studies have addressed the problem of differentiating ADHD from CAPD. Riccio, Hynd, Cohen, Hall et al. (1994) conducted a study that sought to determine if the prevalence of ADHD would be higher in a sample of children diagnosed with CAPD than in normal children. Results indicated that the incidence of ADHD in the sample was 50 percent, which exceeds prevalence in the general population. There was a low incidence of behavioral disorders, however participants with and without ADHD demonstrated more language impairment than expected in the normal population (Riccio et al., 1994).

Children who were referred for the study conducted by Riccio et al. (1994) were most frequently referred for academic difficulties. In order to be part of the research, participants were required to pass a hearing test. In addition, they were required to meet criteria for CAPD based on their performance on a variety of measures. Four measures were administered and children were required to demonstrate impairment on at least two of them to be diagnosed with CAPD. Assessment of ADHD was based on a variety of teacher and parent checklists and a clinical interview.

Results of the study indicate that 30 participants of the 46 who were referred were diagnosed with CAPD. Ages of participants ranged from nine years to 13 years. Fifty percent of the 30 children who met criteria for CAPD also met criteria for ADHD. Of these, 33.3 percent were diagnosed with ADHD/HI and 16.7 percent were diagnosed with ADHD/PI. Further analyses did not support group differences between CAPD-only and CAPD/ADHD on other language measures. Riccio et al. (1994) posit that the comorbidity demonstrated in this research is likely attributable to difficulties making a differential diagnoses rather than to the expression of two distinct disorders.

An earlier study (Ludlaw, Cudahy, Bassich, & Brown, 1983) investigated the performance of children with ADHD on measures used to diagnose CAPD. Specifically, Ludlaw et al. (1983) compared a group of boys with ADHD without language disorders to four other groups. These groups included boys who were language impaired and hyperactive, boys who were language impaired and not hyperactive, reading disabled and hyperactive, and normal controls. Results indicated that boys who were hyperactive performed significantly poorer than other groups on a signal detection task. All four groups demonstrated significant impairment relative to controls on measures of temporal sequencing.

Gascon, Johnson and Bird (1986) assessed a sample of children with ADHD on a variety of neuropsychological measures, including measures of central auditory processing. In addition, they separated children with ADHD into subtypes. Gascon et al. (1986) found high agreement between teacher reports of auditory processing difficulties and impairment on measures of central auditory processing. The second part of the study involved prescribing children who demonstrated impairment on central auditory measures a stimulant medication and then reassessing them for impairment. Results indicated significant improvement in central auditory processing following the medication, and indicated that children with ADHD and central auditory processing impairment were more sensitive to medication. Also, high teacher concordance was found at the later assessment. Gascon et al. (1986) suggest that results of the study question whether or not ADHD and CAPD represent two distinct disorders.

Keith and Engineer (1991) provide further evidence for the role of stimulant medication on performance on measures of central auditory processing in children with ADHD. Children who participated in the study had previously been diagnosed with ADHD. Results indicated that children who were medicated demonstrated significant improvement on measures of auditory processing and auditory vigilance. Keith and Engineer (1991) conclude that results of the study support the premise that children with ADHD were performing at a lower level on measures of CAPD. This also brings implicates the need for future research that looks specifically at treating CAPD with stimulant medication.

STATEMENT OF THE PROBLEM

Central auditory processing is an area of research interest and demonstrates clinical relevance in psychology, neuropsychology, and speech and hearing sciences. Despite the growth in this line of research, major definitional and conceptual problems hinder the application of CAPD to clinical work, especially in the field of psychology. Of particular concern to the current study was the role of CAPD in the assessment and treatment of ADHD.

CAPD is currently not well defined in the literature. Although CAPD is defined as a perceptual deficit in central hearing not caused by peripheral hearing, the definition broadens the scope by highlighting the occurrence of a variety of other difficulties, including attention. Stemming from this definition are problems in diagnosis. Diagnosis is typically made by audiologists, whereas psychologists are apt to diagnosis children with the clinical presentation described in the definition of CAPD as having ADHD.

The American-Speech-Hearing-Language Association (1996) reports a behavioral definition of CAPD that includes an observed deficiency in one or of the following areas: “sound localization and lateralization, auditory discrimination, auditory pattern recognition, and temporal aspects of audition.” Dichotic speech tests are often used in the diagnosis of CAPD, however it has been suggested that diagnosis based on this measure alone is not sufficient.

Cohen (1980) describes children “at risk” for developing CAPD as exhibiting the following behavioral symptoms, “frequently misunderstands oral instructions,” “frequently needs repetition of directions or information,” “may have problems discriminating speech sounds,” “may have spelling, reading or other academic problems,” and “may have behavioral problems.” For many professionals in the field of psychology who work with children with ADHD, this description may sound familiar. That is, CAPD has been described in the literature to be quite similar to ADHD, especially the inattentive subtype. Thus, a major problem is the differentiation of CAPD from ADHD. Moreover, whether or not CAPD is simply an expression of ADHD and is in fact not a separate disorder is a question.

Research prior to the current study that addressed this question typically administered measures of central auditory processing to children with ADHD (Riccio et al., 1994). Although this approach has provided relevant information in conceptualizing the relationship between ADHD and CAPD, how CAPD applies to ADHD remains unclear. Because the research addressing the neuropsychology of ADHD is far ahead of research addressing the neuropsychology of CAPD, applying this knowledge provided more specific information regarding this relationship. In addition, age and gender effects were explored.

Further understanding the relationship of ADHD and CAPD provided information that allows clinicians to assess children that show difficulties in this arena more effectively. Because both disorders may be associated with significant academic difficulties, applying the most appropriate treatment will lead to better outcomes generally (Cacace and McFarland, 1998). Therefore, a better understanding of the relationship of ADHD and CAPD based on patterns of neuropsychological performance was necessary. Such understanding will inform intervention for this group of children.

CAPD may be responsive to treatment, according to one investigation. For instance, Kraus et al. (1997) reports promising research on the “retraining” of central auditory processing networks. Other research (Keith and Engineer, 1991) has supported the effectiveness of stimulants in the treatment of CAPD as it occurs in children with ADHD. It seems likely that children are not receiving appropriate interventions in cases where the diagnoses of CAPD and ADHD are not clearly delineated. The present study has contributed relevant information to providing more appropriate treatment to children diagnosed with CAPD.

Thus, the purpose of this study was to develop a more sophisticated understanding of the construct of auditory processing as a contributing factor in conceptualization of ADHD. By utilizing the present neuropsychological and behavioral formulation for what constitutes ADHD, auditory processing was introduced as a variable that help differentiate between subtypes of ADHD. Specifically, attention and behavior were used as well-established predictors of ADHD and a measure of auditory processing was used as less established predictor.

It was expected that auditory processing would contribute to auditory attention and behavior as a variable that could differentiate between subtypes of ADHD. It was also expected that there would be differences between subtypes on performance on a measure of auditory processing. Additionally, age and gender differences were explored for implications for future research.

Chapter 3: Methods

PROCEDURES

Participants in this study were recruited through an ongoing social competence research project at the University of Texas led by principal investigator Dr. Margaret Semrud-Clikeman. The overarching goal of the project was to investigate neuropsychological variables associated with certain developmental conditions that may contribute to social functioning difficulties among children. Professionals from the central Texas area referred students to this research project after receiving training about social competency difficulties that children with disorders such as ADHD and NVLD may experience. The principle investigator and other research team members provided this information through presentations given to clinicians.

Following the presentations, clinicians were given packets explaining the research protocol and exclusionary criteria. Clinicians shared this information with parents and caregivers who they believed had children who would benefit from participation in the study. Interested parents and caregivers signed a consent form included in the packet and returned it to the research team. After receipt of signed consent forms, a research team member contacted the parents to set up a time for an assessment. The Structured Interview for the Diagnosis of Affective Disorders in Children (SIDAC) was also completed at the time of initial contact. Children signed an assent form when they arrived for testing.

Children with parental consent and who signed the assent form for the project completed a standard battery of measures. The battery of measures was individually administered by a trained doctoral student and took five to eight hours. If necessary, the testing took place over more than one meeting. Intelligence and achievement testing completed in the preceding year was not repeated. After the assessment was completed, a neuropsychological screening report was provided to the family. If appropriate, participants were recruited to participate in a social competency intervention.

Children who had completed the neuropsychological assessment and met criteria for the present study were asked to return for an additional one hour of testing. Parents and caregivers were informed that the additional hour of testing was part of a dissertation study and was voluntary. If interested, a time was scheduled for the participant to complete the additional measures. After the testing was completed, data were filed about the participants' performance on the additional measures used for this study. When appropriate, the additional findings were incorporated into the existing neuropsychological screening reports.

PARTICIPANTS

Thirty participants were recruited for the study. Demographic information about participants is included in Table 2. Children who participated in this study were between the ages of seven and 14 at the time that they were recruited for the current study. All children recruited for this study were required to have intelligence score at least in the low average range (greater than 85) as measured by the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) (Wechsler, 1997). Since a majority of measures are available solely in English, only predominantly English speaking participants were used.

Diagnosis	***Age***	***Gender***	***Ethnicity***
ADHD/PI = 15 (50.0%) ADHD/C & ADHD/HI = 15 (50.0%)	Mean = 11.03 (SD = 2.00)	Males = 25 (83.3%) Females = 5 (16.7%)	Caucasian= 26 (86.7%) Latino = 2 (6.7%) African American = 1 (3.3%) Asian/Pacific Islander = 1 (3.3%)

Table 1: Demographic Information.

Participants were grouped into subtypes of ADHD based on number of hyperactive/impulsive and inattentive symptoms endorsed. To be included in this study, participants reported a negative history of acquired neurological impairment (e.g., traumatic brain injury), specific neurological pathology such as a seizure disorder or brain tumor, and psychotic symptoms. Additionally, children were screened for hearing loss. Children with impaired hearing were excluded from the study.

To be included in the study, participants met diagnostic criteria for ADHD based on parent's completion of the Structured Interview for the Diagnostic Assessment of Children (SIDAC). Children fell into one of three ADHD subtypes, which included ADHD predominantly inattentive (ADHD/PI), ADHD predominantly hyperactive (ADHD/HI), or ADHD combined subtype (ADHD/C). For the purposes of this study, ADHD/HI and ADHD/C were collapsed into one group. ADHD/PI included parental endorsement of more than five inattentive symptoms, ADHD/HI entailed parental endorsement of more than five hyperactive/impulsive symptoms, and ADHD/C referred to parental endorsement of more than five inattentive and more than five hyperactive/impulsive symptoms. The following measures were used to predict group membership.

MEASURES

Independent Measures

SCAN-C and SCAN-A

The SCAN-C (Test for Auditory Processing Disorders in Children- Revised) was developed to assess the perception stage of auditory processing in children ages five whereas the SCAN-A was developed for the same assessment purposes, but for children 12 through 17. The subtests included in the child and adolescent versions are the same; however the items are more difficult in the adolescent version. The test requires that participants repeat stimulus words or sentences. They are not required to demonstrate a cognitive understanding of the phonetic or phonologic differences that exist among speech sounds.

The first two subtests, Filtered Words and Auditory Figure Ground, are sensitized speech tests in which the test items have been distorted in a specific way to decrease intelligibility. The second two subtests, Competing Words and Competing Sentences, are dichotic listening tests in which different words or sentences are presented simultaneously, one to each ear.

The test stimuli for subtest 1, Filtered Words, consist of one-syllable words that have been low-pass filtered at 1000 Hz with a roll-off of 32 dB per octave. The child or adolescent is asked to repeat these muffled words. Three practice and 20 test words are presented to the right ear. Then two practice and 20 test words are presented to the left ear.

Subtest 2, Auditory Figure Ground, assesses the participant’s ability to understand speech in the presence of background noise. One-syllable words were recorded for this task in the presence of multi-talker speech babble noise. The words presented 8 dB higher than the background noise. Two practice words and then twenty test words are presented to the right ear, and then two practice words and twenty test words are presented to the left ear.

Subtest 3, Competing Words, is a dichotic listening task that also assesses ear advantage. The test stimuli consist of one syllable word pairs presented to the right and left ears. The participant hears two words simultaneously, one presented to each ear. First, two practice word pairs and 15 test word pairs are presented, which require the participant to repeat the word heard in the right ear first. Then, a second set of two practice word pairs and 15 test word pairs require the participant to repeat the word heard in the left ear first.

The final subtest, Competing Sentences is also a dichotic listening task. In this task, participants are instructed to direct attention to stimuli presented in one ear while ignoring stimuli presented in the other ear. There are two practice sentence trials and 10 items for each ear.

The SCAN-C was standardized on 650 children between the ages of five and 11 years (Keith, 2000). The sample was based on the general United States population and was stratified by age, gender, race/ethnicity, geographic region, and parent education level. Children were also required to be able to take the test in English without modification and were required to have normal peripheral hearing.

Internal consistency coefficients for the four subtests were calculated using Cronbach’s Alpha. The SCAN-C composite test reliability coefficients range from .86 to .92 whereas the reliability coefficients for the four subtests range from .56 to .89. SCAN-

C test-retest reliabilities range from .65 to .82 for the five to seven year-olds and .67 to .78 for the eight to 11 year-olds.

Keith (2000) also provides information regarding criterion and construct validity. Criterion validity was reported through correlations between the original SCAN and SCAN-C. The correlations for the subtests range between .31 and .72 and the correlation for the composite standard score is .79. Construct validity was measured through discriminant validity. A study was conducted on a group of 144 children who had been diagnosed with CAPD. Their performance on the SCAN-C was compared to normative data. Results indicate that children with CAPD performed significantly worse than children represented in the normative data.

SCAN-A (Keith, 1997) was standardized on a sample of 125 participants between the ages of 12 and 50 years of age. Participants were obtained from 21 sites representing major geographic regions of the United States. The sample was stratified by age, gender, and race/ethnicity based on United States census information.

The SCAN-A reliability coefficients were obtained using Cronbach's Alpha. The reliability coefficient for the Total Test was .77 and the subtest reliability coefficients range between .46 and .69. Thirty-eight participants were included in the test-retest study. The test-retest coefficient for the Total Test score was .69 and the standard error of measurement was 2.8.

Keith (1997) offers information regarding the construct and concurrent validity of the SCAN-A. A discriminant analysis compared participants with normal auditory processing abilities with participants who have central auditory processing disorders. Twenty-five participants with CAPD were matched to 25 normal controls on the basis of age, gender, and ethnicity. The SCAN correctly identified individuals as having CAPD 86 percent of the time. The concurrent validity of the SCAN-A was assessed by comparing performance on the SCAN-A with the SCAN. Results indicate a correlation between the two Total Scores of .49 before attenuation and .59 after attenuation. For the purposes of this study, the total standard score obtained from each participant will be used as the measure of auditory processing.

Test of Variables of Attention- Auditory (T.O.V.A.-A)

The T.O.V.A.-A. is an individually administered computerized test developed to assess attention and impulse control in normal and clinical populations. The T.O.V.A. specifically measures attentional and impulse control processing in three areas: 1) omissions; 2) commissions; 3) response time; and 4) response time variability (Greenberg, 2000).

During the T.O.V.A- A, the stimuli include two easily discriminated audible tones. The target is “Middle G” and the non-target is “Middle C,” which are played through external speakers on the computer. One of the two stimuli is presented for 100 milliseconds every two seconds during the first half of the test. The stimulus is presented 22.5% of the trials during this first half of the trials (stimulus infrequent condition). The stimulus is presented 77.5% of the time during the second half of the test (stimulus frequent condition. The task is for the participant to respond to the appropriate target as soon as possible. The varying target/non-target ratio allows for the examination of effects of differing response demands on inattention and impulsivity (Leark, Dupuy, Greenberg, Corman, & Kinschi, 2000).

The T.O.V.A. was standardized on a normative sample of 2,551 children between the ages of 6 and 19. The sample was predominantly Caucasian and was recruited from metropolitan Minneapolis, Minnesota and suburban schools. To calculate reliability quotients for the test, Pearson product coefficients (r) were computed for all variables across all conditions. Coefficients range from .63 to .90 across conditions. Since it is an auditory continuous performance test, it is not to be used on hearing-impaired children. The participant is instructed to press a button every time he or she hears the target around, but only to press down until he or she hears the "click." Additionally, participants are instructed to press the button as quickly as possible, but to also be accurate. They are also instructed to press the button only once for each target note (Leark et al., 2000).

In order to determine validity for the T.O.V.A.-A, the percentage of omission errors, percentage of commission errors, mean response time, response time variability and d prime across both conditions by quarter, halves, and totals were entered into a principal components factor analysis with a varimax rotation (N = 2551). The factorial analysis yielded five loadings accounting for 86% of the variance. The factors were response time, percentage of commission errors, percentage of omissions, stimulus frequent conditions, percentage of commission errors stimulus infrequent, and percentage of omission errors stimulus infrequent.

In contrast to the visual version of the T.O.V.A., the auditory version of the T.O.V.A. partials out commission errors across the two conditions. An analysis of covariance controlling for age and gender was performed to compare total variable scores between the visual and auditory versions. All mean score between test differences were significant ($p < .001$) (Leark & al., 2000).

Behavioral Assessment System for Children (BASC)

The BASC was designed as a behavioral assessment of children through parent, teacher, and self-ratings (Reynolds & Kamphaus, 1992). The measure includes clinical behaviors as well as adaptive behaviors. Score are reported as T-scores, with score greater than 65 on clinical scales considered significant and scores less than 35 on adaptive scales considered significant. The BASC was standardized n a sample that included 3,065 Teacher Rating forms, 3,065 Parent Rating forms, and 9,861 self-report forms. The sample was stratified on age, gender, ethnicity, and geographic region based on 1990 U.S. census data.

The BASC Parent Rating Scale (BASC-PRS) is comprised of three composite scores including Externalizing Problems, Internalizing Problems, and Adaptive Skills. There is also a Behavioral Symptoms Composite. The Externalizing composite score is comprised of three scaled scores, which include Hyperactivity, Aggression, and Conduct Problems. The Externalizing scale was used as a measure of externalizing behavioral problems in the current study for two reasons. First, prior research has supported the use of all scales at discriminating between subtypes (Ostrander, Weinfurt, Yarnold, & August, 1998; Vaughn, Riccio & Hynd, 1997). Second, these scales are highly correlated with coefficients ranging from the .70's to the .80's.

Measure	**Variable Type**	**Construct**	**Score to be Used**
SCAN-C and SCAN-A	Predictor	Auditory Processing	Total Test Standard Score
T.O.V.A.-A	Predictor	Auditory Inattention	Total Commissions
BASC	Predictor	Externalizing Behavioral	T-score from Externalizing Scale

Table 2: Predictor Variables.

EXPERIMENTAL HYPOTHESES

Below, each research question and related hypothesis is described. Additionally, expected findings based on theory or previous research is described. Following discussion of research questions and hypotheses is an outline of planned data analyses. Discriminant function analysis was used to classify participants into groups based on their performance on measures of externalizing behavioral problems, which was measured by parent report on the BASC; auditory processing ability as measured by the SCAN-A or SCAN-C; and auditory attention, which was assessed by performance on the

T.O.V.A.-A. The hit rate was used as the number of correct classifications of participants into subtypes.

Research Question 1

Does parent's perception of externalizing behavioral problems alone accurately classify children with ADHD into their correct subtypes?

Hypothesis 1

1. Parent report of externalizing behavioral problems, as measured by t-scores on Externalizing Scale of the BASC, will separate ADHD/PI from ADHD/HI and ADHD/C.

    1a. The hit rate, measured by the number of children correctly classified into their ADHD subtype divided by the total number of children, will be greater when t-scores from the Externalizing Scale of the BASC are used than the hit rate by chance for children with ADHD/HI and ADHD/C.

Rationale 1

According to the DSM-IV-TR (American Psychiatric Association, 2000), ADHD/PI differs from ADHD/C in the latter's symptoms of hyperactivity and impulsivity. Lack of behavioral inhibition and impulsivity often leads to behavioral problems. For children with the inattentive subtype, difficulties with listening, completing work, making careless mistakes, appearing disengaged, and forgetfulness are problems that are attributed to inattention and do not typically appear as behavioral problems, but rather appear as sluggishness and lead to academic problems.

CAPD overlaps with ADHD/PI specifically in the area of listening, which can lead to difficulties similar to children with ADHD. However, CAPD is defined as a perceptual problem, not a behavioral or attentional problem. Thus, it would be expected that children with ADHD and auditory processing impairment will not be rated as having more behavioral problems that children with ADHD.

Research Question 2

Will externalizing behavior and auditory processing together accurately classify participants into their appropriate ADHD group membership?

Hypothesis 2

2. The hit rate for a combination of externalizing behavior measured by the BASC and auditory processing measured by the SCAN-C and SCAN-A will be greater than the hit-rate by chance.

    2a. The hit rate, measured by the number of children correctly classified into their ADHD subtype divided by the total number of children, will be greater when t-scores from the Externalizing Scale of the BASC and the SCAN are used than the hit rate by chance for children with ADHD/HI and ADHD/C.

Rationale 2

Children with ADHD/PI have been shown to exhibit more academic problems than children with ADHD/HI. Weiler et al. (2002) found that children with ADHD/PI were more likely have a sluggish cognitive style and to be described by teachers as slow. Unlike children with ADHD/HI or ADHD/C, Gascon et al. (1986) found that teachers were more likely to report children with ADHD/PI as having auditory processing difficulties and that these children were also more likely to respond positively to stimulant treatment for ADHD.

Research Question 3

Does the combination of externalizing behavior, auditory processing, and auditory attention have a higher hit-rate than the combination of externalizing behavior and auditory processing in classifying participants into their accurate ADHD subtype group memberships?

Hypothesis 3

3. The hit rate for a combination of all three variables (externalizing behavior, auditory processing, and auditory attention) will not be more accurate in discriminating between ADHD/PI and ADHD/HI and ADHD/C combined than the hit rate for externalizing behavior and auditory processing alone.

Rationale 3

Results regarding whether attention is multimodal or whether impairment can occur across just one modality of attention (visual or auditory) has been mixed (Cacace & McFarland, 1998; Riccio, Cohen, Hynd, & Keith, 1996). Additionally, the majority of studies that have investigated children with ADHD's performance on continuous performance tests have generally used a visual continuous performance test rather than an auditory test. Results of studies that have compared performance on visual continuous performance tests between subtypes of ADHD have found that children with ADHD/HI typically show an impaired performance whereas children with ADHD/PI generally do not. However, these studies have not employed an auditory measure of attention. Based on support for auditory processing difficulties in children with ADHD/PI, auditory attention is likely impaired as well. If auditory attention and auditory processing represent the same construct rather than auditory processing representing a distinct construct, then the addition of auditory attention in group classification should not improve the hit rate.

Research Question 4

What are the significant differences between the group of ADHD/PI and the group of ADHD/HI and ADHD/C combined on measures of externalizing behavior problems as perceived by parents, auditory processing, and auditory attention?

Hypothesis 4

There will be a significant difference between the centroids of the ADHD/PI and ADHD/HI and ADHD/C combined.

Rationale 4

An overarching research question posed in this study was whether CAPD represents a distinct disorder or whether CAPD represents a manifestation of ADHD/PI in which auditory attention is the prominent symptom. If a neuropsychological correlate of ADHD/PI is auditory processing, which clinically presents as auditory attention impairment, then the two measures should not have separate discriminate ability. Rather, they should discriminate ADHD/PI from ADHD/HI and ADHD/C equally well.

EXPLORATORY QUESTIONS

One area of interest for further investigation was the role of gender and age in the neuropsychological profiles of children with ADHD. According to the DSM-IV-TR, (American Psychiatric Association, 2000) females are significantly more likely than males to be diagnosed with ADHD/PI. Males are more likely to be diagnosed with ADHD/C or ADHD/HI. Investigating the role of auditory processing impairment in the subtypes based on gender was planned to identify patterns that will assist in differentiating groups.

Additionally, age has been shown to be a factor in the manifestation of ADHD. That is, as children develop into adolescents symptoms of hyperactivity and impulsivity tend to subside. Investigating whether symptoms of auditory processing impairment subsided provided valuable information in the differentiation of subtypes.

METHOD OF DATA ANALYSIS

Discriminant function analysis (DFA) was used as the primary method of data analysis. DFA was applied due to its two purposes in research studies. First, it was useful for describing differences between groups. Second, it was useful for the purpose of classifying subjects into groups on the basis of a battery of measurements. In the latter case, the hit rate was the number of correct classifications and is of most use for interpretation. In the former purpose, major differences among groups were indicated through the use of uncorrelated linear combinations of the original variables (discriminant functions).

DFA was especially appropriate for the present study because it allowed for use of the already formed groups while being parsimonious. Thus, the hit rate method allowed for the measures of auditory processing, auditory attention, and externalizing behavior to be used to classify subjects into groups based on their ADHD subtype diagnosis. The overriding research question that guided this project regarded the role of auditory processing in ADHD subtypes. Because of the questions in the literature regarding whether auditory processing represents a distinct construct or is instead a part of the auditory attentional system remains unanswered, however information gleaned from this study furthers understanding in this area.

The use of DFA in analysis of data clarified the role of auditory processing in ADHD by using multiple predictors of ADHD. These included the use of measures of externalizing behavior, auditory processing and auditory attention to predict group membership that was previously established. This method allowed the researcher to determine if auditory processing makes a unique contribution to the accuracy of predicting group membership, or conversely, if auditory processing and auditory attention when used together do not add to accuracy in prediction.

There were limitations in the application of DFA to analysis of these data. The primary limitation related to the sample size. In an optimal application of DFA, participants would be divided into two groups for cross-validation purposes. Although the present study did not allow for this due to the small sample size, future studies may replicate these results and offer further information.

Chapter 4: Results

DISCRIMINANT FUNCTION ANALYSIS

Discriminant Function Analysis (DFA) was used to test hypotheses one through four. DFA was used to determine how accurately the three predictor variables when used together predicted ADHD subtype when compared to chance. DFA was also used to determine the accuracy of prediction when externalizing behavior was used as a sole predictor and when externalizing behavior was used with auditory processing as joint predictors. Additionally, DFA was applied in order to determine the relative weights of each predictor variable in classifying cases into diagnostic categories of ADHD/PI or ADHD/C and ADHD/HI.

Initially the three predictor variables, which included externalizing behavior, central auditory processing, and auditory processing, were included to determine the equation that best discriminates between subtypes of ADHD. See Table 3 for the hit rate table. Next, externalizing behavior was used alone to classify cases. See Table 4 for the hit rate table. Lastly, auditory processing and externalizing behavior were used to together to classify cases. See Table 5 for the hit rate table. The hit rates for each of these analyses were calculated by using the squared Mahalanobis distance. Hit rates were then compared to the chance hit rate, a hit rate representing the chance that cases will be correctly classified 50 percent of the time.

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C & ADHD/HI*	***Total***
Actual ADHD/PI Actual ADHD/C & ADHD/HI	11 4	4 11	15 15
Percentage	73.3% 26.7%	26.7% 73.3%	100% 100%

Table 3: Hit Rate Table for All Three Variables.

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C & ADHD/HI*	***Total***
Actual ADHD/PI Actual ADHD/C & ADHD/HI	12 3	3 12	15 15
Percentage	80.0% 20.0%	20.0% 80.0%	100% 100%

Table 4: Hit Rate Table for Externalizing Behavior.

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C& ADHD/HI*	***Total***
Actual ADHD/PI Actual ADHD/C & ADHD/HI	4 11	11 4	15 15
Percentage	73.3% 26.7%	26.7% 73.3%	100% 100%

Table 5: Hit Rate Table for Externalizing Behavior and Auditory Processing.

AGREEMENT ANALYSES

In order to determine the significance of the agreement between the actual and predicted diagnoses, DFA was utilized using a "within groups" design. This analysis resulted in the hit rates provided in the Table 6 below. Actual numbers were converted to proportions in order to obtain the g-index and Cohen's kappa as measures of association. Hit rates remained the same using externalizing behavior alone, using externalizing behavior and auditory processing, and when all three variables were used together. Indicated by the g-index of 0.54, agreement was different from zero in all three cases ($p \leq 0.05$). Also, the kappa value of 0.51 indicates that results were different from zero ($p \leq 0.05$).

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C & ADHD/HI*
Actual ADHD/PI	0.37	0.13
Actual ADHD/C & ADHD/HI	0.1	0.4

Table 6: Proportions for Agreement Analyses.

Results of the analyses provided evidence to support hypothesis one. According to the hit rate table, externalizing behavior accurately classified cases significantly better than would be expected by chance. Specifically, when used alone as a predictor variable, externalizing behavior as measured by the BASC correctly classified participants into ADHD subtypes 80 percent of the time.

Results of the analyses also provided evidence to support hypothesis two. Based on information provided in the hit rate table, when externalizing behavior is used with auditory processing, cases are correctly classified 73.3 percent of the time. This provides evidence that externalizing behavior and auditory processing are significantly more accurate at classifying cases by ADHD subtype than chance.

DFA provided evidence to support hypothesis three. Specifically, externalizing behavior, auditory processing, and auditory attention when used together as predictor variables predicted group membership better would be expected by chance. As indicated in the hit rate table, when these predictor variables were used together they accurately classified cases 73.3 percent of the time.

DFA was useful in testing the fourth hypothesis, which involved exploring relative weights of predictors for ADHD/PI and ADHD collapsed group. Weights were obtained through Mahalanobis' Distance and are summarized in Table 7. According to the results, externalizing behavior had the most predictive power for both groups. There were no significant differences between functions of predictor variables between groups ($\underline{p} \geq 0.05$).

	ADHD/PI	*ADHD/C & ADHD/HI*
Externalizing Behavior	0.555	0.679
Central Auditory Processing	0.315	0.357
Auditory Attention	0.116	0.112

Table 7: Predictor Variable Weights.

In addition to summarizing predictor variables weights, group means for predictor variables were compared. There were no significance differences between group means for measures of auditory processing and auditory attention ($\underline{p} \geq 0.05$). In contrast, there was a significant difference between group centroids for externalizing behavior ($\underline{p} \leq 0.05$).

Planned Exploratory Analyses

Planned analyses were conducted to explore the effects of age and gender. Due to the small number of female participants (N = 4), gender differences were not calculated. However, analyses provided descriptive information regarding the make-up of the groups based on gender. In the ADHD/PI group there were three females and 12 males. Of the males, there were three nine-year-olds, one 10-year-old, one 11-year-old, three twelve-year-olds, once 13-year-old, and three 14-year-olds. Of the females, there were two 11-year-olds and one fourteen-old. In the ADHD collapsed group there were 13 males and two females. Of the males, there was one seven-year-old, two eight-year-olds, two nine-year-olds, two 10-year-olds, two 11-year-olds, three 12-year-olds, and one 14-year-old.

The ethnicity of groups based on gender was also explored. In the ADHD/PI group there were 11 Caucasians, one Latino, and one Asian/Pacific Islander participant. Eleven ADHD/PI males were Caucasian and two females were Caucasian. One male participant was Latino and one female participant was Asian/Pacific Islander. In the collapsed group 13 participants were Caucasian including 12 males and one female. One female in the collapsed group was Latino and one male was African American.

Exploration of age effects yielded mixed results. The relationship between age and performance on the three predictors was measured by a Pearson correlation. For externalizing behavior and auditory attention, there was not a significant relationship. However, there was a significant relationship between age and auditory processing ($p \leq .05$).

Secondary Analyses

Secondary analyses were conducted to gain further understanding of the data after initial planned analyses were conducted. One area of analysis looked more specifically at the relationships between variables. There were no significant correlations found between predictor variables. Table 8 summarizes the p-values obtained. In addition, the correlation~~s~~ was calculated between TOVA commissions, which was used as a predictor variable, and TOVA omissions, which was collected but not used for prediction. Results indicated a significant correlation between these variables ($p \leq .05$).

	TOVA Commissions	*BASC Externalizing*	*SCAN*
TOVA Commissions	1.00	-.137	0.096
BASC Externalizing	-0.137	1.00	-0.404
SCAN	0.096	-0.404	1.00

Table 8: Predictor Variable Correlations.

Secondary analyses were also conducted to explore the mean scores of groups on measures used. Mean scores were examined in relation to normative data. Mean scores and standard deviations for ADHD/PI and the collapsed group are listed in Tables 9 and 10, respectively. The TOVA and SCAN use standard scores, which have a mean of 100. The BASC uses t-scores, which have a mean of 50. On the BASC, elevated scores indicate behavioral problems. On the TOVA scores below 85 indicate disturbance in attentional functioning. On the SCAN, scores below 85 indicate disturbance in auditory processing.

	Mean	*Std. Deviation*
TOVA Commissions	82.46	23.97
BASC Externalizing Behavior	57.87	14.69
SCAN	74.6	24.29

Table 9: Mean Scores and Standard Deviations for ADHD/PI.

	Mean	*Std. Deviation*
TOVA Commissions	67.6	27.21
BASC Externalizing Behavior	73.13	10.13
SCAN	78.87	14.93

Table 10: Mean Scores and Standard Deviations for ADHD/HI and ADHD/C.

SUPPLEMENTARY ANALYSES

Supplementary analyses were conducted to explore the usefulness of auditory attention and auditory processing as predictor variables when used without externalizing behavior. Results indicated that when auditory attention and auditory processing were used together as predictor variables they accurately predicted group membership 63.3 percent of the time, which was not significantly different than that which would be accurately classified by chance. When auditory attention was used as a predictor variable, cases were correctly classified 60 percent of the time, which was not significantly different than what would be expected by chance. When auditory processing was used as a predictor variable, cases were accurately classified 50 percent of the time, which is not significantly differently that what would be expected by chance. See tables 11, 12, and 13 included below for further information.

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C & ADHD/HI*	***Total***
Actual ADHD/PI Actual ADHD/C & ADHD/HI	6 9	9 6	15 15
Percentage	66.7% 33.3%	33.3% 66.7%	100% 100%

Table 11: Hit Rate Table for Auditory Processing and Auditory Attention.

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C & ADHD/HI*	***Total***
Actual ADHD/PI Actual ADHD/C & ADHD/HI	7 8	8 7	15 15
Percentage	66.7% 33.3%	33.3% 66.7%	100% 100%

Table 12: Hit Rate Table for Auditory Attention.

Diagnosis	*Predicted ADHD/PI*	*Predicted ADHD/C & ADHD/HI*	***Total***
Actual ADHD/PI Actual ADHD/C & ADHD/HI	8 7	7 8	15 15
Percentage	53.3% 46.7%	46.7% 53.3%	100% 100%

Table 13: Hit Rate Table for Auditory Processing.

Chapter 5: Discussion

DISCUSSION OF MAJOR FINDINGS

Central auditory processing is a critical ability for children to develop due to its role in enabling children to construct accurate meaning of information relevant to their home, school, and social environments. Children who have difficulty in this area often struggle to interact effectively and behave appropriately due to their misinterpretation of auditory stimuli. Thus, deficits in central auditory processing ability can be in obstacles in children's development.

Children who demonstrate deficits in their ability to process auditory stimuli are often diagnosed with Central Auditory Processing Disorder (American Speech-Language-Hearing Association, 1992). Since its introduction 40 years ago, CAPD has been a controversial diagnosis (Musiek & Baran, 1987). The controversy surrounding CAPD pertains largely to diagnostic and conceptual issues. CAPD is conceptualized as a modality-specific disorder; however, children diagnosed with CAPD often demonstrate impairments in others areas such as attention (McFarland & Cacace, 1995). The goal of the present research was to address the relationship between CAPD and attention.

In order to investigate this relationship, central auditory processing was assessed in a group of children diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD) who did not have learning disabilities and whose IQ's were above 85. Participants were administered measures of externalizing behavior, auditory attention, and auditory processing. Data analysis involved determining how well these measures were able to predict subtype of ADHD.

Discriminant Function Analysis (DFA) was applied to examine the predictive ability of the measures used. Results provided information regarding the usefulness of each variable in differentiating between subtypes of ADHD as well as the effectiveness of the variables when used together were able to differentiate between subtypes. According to results of the present study, externalizing behavior is the most robust predictor for differentiating children with ADHD into accurate subtypes. It was found that when used alone as a predictor variable, externalizing behavior as measured by the BASC accurately predicted group membership for 80 percent of participants.

DFA indicated that auditory processing, when used with externalizing behavior, correctly classified ADHD subtype 73.3 percent of the time. This classification was significantly greater than what would be correctly classified by chance, which would have been 50 percent. However, this was a slightly lessaccurate classification rate than when externalizing behavior was used alone, which was 80 percent. These findings indicate that when the SCAN, which measures auditory processing, was used with the BASC as predictor variables 73.3 percent of cases were accurately classified into their diagnosed subtype of ADHD whereas when the BASC was used alone 80 percent of cases were correctly classified into their appropriate subtypes.

According to the results of DFA, when auditory attention, which was measured by the TOVA, was used with externalizing behavior and auditory processing participants were accurately classified into subtype 73.3 percent of the time. The accuracy rate was the same as when externalizing behavior and auditory processing were used together. This level of accuracy was significantly greater than the chance rate of 50 percent, but less than when externalizing behavior was used alone. It was equivalent to the classification rate of 73.3 percent, which resulted from using predictor variables externalizing behavior and auditory processing and less that the classification rate of 80 percent, which was obtained when externalizing behavior was used alone.

In summary, the discriminant function analysis revealed that when externalizing behavior was used as a sole predictor variable, participants were accurately classified into ADHD subtypes 80 percent of the time. This was the highest accurate classification rate found by DFA. Auditory processing and auditory attention used with externalizing behavior and auditory processing alone with externalizing behavior resulted in an accurate classification rate of 73.3 percent, which was significantly greater than chance but less than that achieved by externalizing behavior alone.

Differences in group centroids of ADHD subtypes were examined to determine if the predictor variable weights were different between subtypes. Results indicated that there were no significant differences between groups on measures of auditory processing and auditory attention. However, examination of group means revealed a significant difference between ADHD subtypes on externalizing behavior.

Thus, initial analyses indicated externalizing behavior to be the most effective predictor of ADHD subtype. Although the results indicated that including auditory attention and auditory processing did not increase accurate classification, it is not suggested that these variables are not useful. For 20 percent of cases, externalizing behavior was not an effective predictor variable when used alone.

Case by case analysis of data revealed an interesting pattern that leads to speculation regarding cases that were not accurately classified by externalizing behavior alone. These cases were included in the 20 percent who were not accurately classified by use of externalizing behavior alone. An overlap between BASC scores was found for ADHD/PI cases and ADHD/C and ADHD/HI cases. For the general group of accurately classified cases, cases with BASC scores below 67 were classified as ADHD/PI and cases that had BASC scores above 67 were classified as ADHD/HI or ADHD/C. However, for cases that had BASC scores between 63 and 72, the BASC was not sufficient. In these cases, a low score on the SCAN differentiated cases. For this group of "overlap" cases, ADHD/PI cases had an average score of 54 on the SCAN whereas ADHD/C and ADHD/HI cases had an average score of 77 on the SCAN. See Table 11 for a summary of diagnoses and scores.

Diagnosis	*BASC Score*	*SCAN Score*	*TOVA Score*
ADHD/PI	50	103	60
ADHD/PI	58	40	65
ADHD/PI	56	97	68
ADHD/PI	44	89	85
ADHD/PI	62	80	90
ADHD/C	91	49	58
ADHD/C	75	80	58
ADHD/C	71	40	62
ADHD/C	88	75	67
ADHD/C	72	89	67
ADHD/C	65	40	69

Table 14: Cases in with BASC "Overlap" Scores.

Planned exploratory analyses were conducted to provide information about age and gender effects. The number of female participants was too low to conduct analyses regarding gender differences. Age effects were revealed for auditory processing. Whereas externalizing behavior and auditory attention were found to be stable across ages, there was a significant relationship between age and performance on the measure of auditory processing.

According to the results of the Pearson correlation, as participants ages increased their performance on the SCAN worsened. However, it cannot be inferred from this finding that auditory processing ability is lower in older than younger participants. It is more likely that this finding is a reflection of the normative data that SCAN scores are based on. Participants who 12 years old and older were administered the SCAN-A, which uses the same set of normative data for all users of the test regardless of age, The SCAN-C, which was administered to children under the age of 12, uses age specific normative data. Thus, participants who 12 and older were subjected to the same norms that older adolescents and adults are subjected to, which likely resulted in lower standard scores.

Secondary analyses were conducted to examine participants' performance on measures when compared to normative data. For ADHD/PI and the collapsed group including ADHD/HI and ADHD/C mean scores for auditory processing and auditory attention were in the impaired range. The mean for externalizing behavior for ADHD/PI was in the normal range when compared to normative data. For ADHD/HI and ADHD/C, mean scores for all variables were in the impaired range.

INTEGRATION OF FINDINGS WITH LITERATURE

Results of the present study, when interpreted in reference to existing literature examining neuropsychological presentations of ADHD, enrich the existing understanding of the role of auditory processing in ADHD. The tendency for children with CAPD to also meet diagnostic criteria for ADHD has led to an area of research that has investigated the relationship between these disorders. The current study measured auditory processing, auditory attention, and externalizing behavior in children with ADHD to address this relationship specific to ADHD subtype.

The diagnostic process of a child who demonstrates difficulty processing auditory information is complicated due to the overlap of symptoms of CAPD with symptoms of ADHD. According to Cacace and McFarland (1998), a child's diagnosis of ADHD or CAPD is dependent on whether the child is being evaluated by a psychologist or audiologist. The American-Speech-Language and Hearing Association (1992) includes attention, memory, and academic functioning as correlates of CAPD. Difficulty listening is one of multiple criteria used to diagnose children with ADHD (American Psychiatric Association, 2000).

Results of the present study indicated externalizing behavior is the most effective predictor of ADHD subtype. This finding is congruent with the diagnostic criteria used to classify children into ADHD subtype (American Psychiatric Association, 2000). According to diagnostic criteria, children with ADHD/C and ADHD/HI are characterized as demonstrating more behavioral problems than children who are diagnosed with ADHD/PI. The mean for ADHD/PI on externalizing behavior was within normal limits whereas the mean for ADHD/C and ADHD/HI were in the clinically significant range. However, case by case analysis that for children whose behavior was not sufficient, further assessment may be necessary for differential diagnosis. The present research indicates that the use of neuropsychological measures of auditory processing and auditory attention provide a more detailed picture of a child's neuropsychological functioning when used in conjunction with behavioral measures for ADHD diagnosis. This is especially true for children who are reported to have behavioral problems in the borderline clinical range.

Prior research that has investigated auditory processing ability in children with ADHD has put forth mixed results. Research has indicated that children with ADHD performed significantly worse on a task of auditory processing than controls (Ludlaw et al., 1983). This finding is consistent with results of the present study. The latter study indicated that children who were hyperactive performed the poorest on the measure, which is not consistent with the present study. This difference may be due to the difficulty measuring auditory processing and that the latter study used a measure of auditory processing that tapped into abilities other than auditory processing, such as attention and control.

Another study looked for congruence between teacher reports of difficulty listening and performance on a measure of auditory processing in children with ADHD (Gascon et al., 1986). Significant agreement was found between the two, which is consistent with the present results and indicates that children reported by parents to have behavioral problems related to ADHD also perform more poorly on measures of auditory processing. The present study enriches the existing literature base by applying neuropsychological measures of auditory processing to children with ADHD while also looking at differences between subtypes. The findings indicate impairment of auditory processing in all subtypes of ADHD and do not suggest the use of measures of auditory processing to differentiate between subtypes.

Prior research has assessed performance of children with ADHD on measures of attention. ADHD is usually diagnosed using visual attention tasks (Cacace & McFarland, 1998). There is debate regarding whether inattention is modality-specific, meaning whether a child with ADHD may exhibit problems with only auditory or visual attention. The present study is based on the underlying premise that there are multiple aspects of attention which may include sustained attention, vigilance, and more complex forms of attention such as being able to divide attention between tasks (Teeter & Semrud-Clikeman, 1994). Although there is research that has conceptualized attention as being modality specific (Bedi et al., 1994), the current research conceptualized attention as being cross-modal (Cacace & McFarland, 1998). Thus, the current study applied a measure of auditory attention in order to assess vigilance.

Previous research has investigated whether measures of auditory attention can be used to differentiate children with CAPD from children with ADHD. Riccio et al. (1996) found that auditory attention was not useful in differentiating children in these two groups. The present study investigated whether a measure of auditory attention is useful in differentiating children with ADHD into subtypes. Results indicated that this measure is not effective for this purpose either.

The current research findings regarding age and gender effects of ADHD are consistent with existing literature (American Psychiatric Association, 2000). Specifically, females were underrepresented in the present study, which is consistent with past findings that ADHD occurs more frequently in males than in females. Analysis of age effects did not indicate a change in externalizing behavior or auditory attention. This finding is consistent with past literature due to the narrow range of ages included in the study. Auditory processing was found to be affected by age; however no past research was available for comparison. It is unclear whether this finding is of interpretive significance, or whether it is an artifact of the measure used to assess auditory processing. Because the SCAN-A and SCAN-C were used due the age range included in the study, it is possible that age effects were due to changes in normative data rather than due to real age differences in auditory processing ability.

CLINICAL IMPLICATIONS

The clinical implications of this study are relevant to a variety of professionals who work with children and adolescents that have diagnosed ADHD or demonstrate problems processing auditory stimuli. Additionally, clinical implications have a secondary benefit for parents and caregivers of this group of children. The ensuing discussion of clinical research will link the present findings to multiple contexts in which this group of children functions.

The results of the current study provide information relevant to professionals who diagnose and treat children with ADHD. Findings support the necessity of using a full neuropsychological battery of tests in addition to behavioral measures to capture the nature of inattentive symptoms. Although the behavioral measure may initially be most effective in predicting subtype of ADHD, having a better understanding of a child's cognitive functioning will clarify diagnostic questions and contribute to treatment planning. Because ADHD represents a constellation of behavioral and cognitive problems, behavioral and neuropsychological assessment is warranted (Rapport, 1991).

Results tap into the necessity of using a full battery that addresses sensitivity and specificity of neuropsychological measures. It is likely that although the present study did not find a significant correlation between the SCAN and the TOVA, that they are related. When used as predictor variables they did not contribute unique information in differentiating between cases. The SCAN contends that it is measures auditory processing, however there are questions of its face validity.

Future research with a larger sample size may likely find a significant correlation between the SCAN and TOVA. When interpreting measures of auditory processing, it is imperative that professionals take into account that the SCAN may be more sensitive than specific. Of greater concern is that it is likely sensitive to weaknesses in the attentional system. This concern further underscores the need for clinicians to administer a more complete battery than the one used in the present study. More specifically, this concern brings to light the question of whether the SCAN is an appropriate measure of auditory processing.

For professionals who assess children within a school system or within private practice, the findings of this study have implications for how resources may best be used and how psychological testing can maintain standards of practice. Based on results of the study, use of the SCAN in assessment of ADHD is not warranted. Not only does the SCAN fail to measure what it purports to measure, using the SCAN in an assessment may lead to misdiagnosis. With the present limits placed on psychological testing in public and private settings, careful selection of measures is imperative. Using measures that are specific and have face validity is critical to maintaining ethical standards. The results of the current study indicate that by using the SCAN, professionals risk misusing funds at best and at worst providing families with misinformation.

Findings provide information for treatment and intervention. By using a behavioral measure in conjunction with neuropsychological measure, treatment and intervention can be tailored to meet the specific needs of individual children. Using a measure of externalizing behavior will not provide sufficient information to design appropriate intervention. A child diagnosed with a subtype of ADHD based only on a behavioral measure will not have been assessed for underlying areas of functioning that are contributing to the overt behavior. By conducting a neuropsychological battery, intervention may also include addressing auditory processing and auditory attention, which may prevent behavioral problems.

The present findings highlight the need to use measures of psychological assessment that will provide accurate information. It is critical to the treatment of children with ADHD that treatment recommendations are based on sound results of psychological assessments. The SCAN provides information in psychological assessment that cannot be clearly interpreted. Thus, treatment recommendations based on the use of the SCAN in the assessment are problematic.

The results of the present study are also applicable to teachers and caregivers who interact with children with ADHD on regular basis. Teachers and caregivers who work with a child with ADHD and have information related only to the child's behavior will miss out on potentially more effective means of addressing behavioral problems. Because teachers and caregivers rely on psychological assessments to provide diagnostic and treatment information, it is imperative that assessments given in the school setting provide accurate information. For instance, if a child is diagnosed with CAPD based on his or her performance on the SCAN, the teacher and caregiver will intervene based on the knowledge that this child has impaired auditory processing. Thus, the child in this situation may miss out on interventions targeting his or her attentional system.

LIMITATIONS

The current study has several limitations. These limitations are related to the sample used and the methodology. In regards to the sample, the ability to generalize findings is limited by demographic factors. The sample used was largely homogeneous, with an overrepresentation of Caucasians. Additionally, there was an overrepresentation of males, which hinders the application of findings to females.

There are also limitations related to the research design. Although a control group was not necessary in the DFA computation, having a control group would have enriched the post-hoc analyses. In addition, the small sample size was a limitation. With a larger sample, it would have been possible to conduct a cross validation of DFA results. A larger sample size would have also provided a diverse enough sample to look more specifically at age and gender effects.

Other limitations based on the use of the SCAN as a measure of auditory processing. The SCAN was selected for use in the study because of its wide application in research and practice and the limited number of measures of auditory processing available. However, the SCAN is problematic due to its posited relationship with the TOVA, the measure of auditory attention, which suggests that the SCAN is more sensitive than specific. It may also suggest that the SCAN did not measure auditory processing and instead measured auditory attention, thereby possibly detracting from results.

RECOMMENDATIONS FOR FUTURE RESEARCH

Current findings provide implications for future research. First, a replication of the present study with a sample large enough for cross-validation is warranted. Have a larger sample that would also allow for a more detailed analysis of age and gender effects. Other recommendations are related to measures used.

Future studies that use a more complete battery of neuropsychological measures are warranted. For instance, it would be useful to use a visual measure of attention in addition to an auditory measure as this would further clarify the cross-modality of attention. Administering measures of verbal abilities, such as abstract verbal reasoning and reading comprehension will also be useful to investigate as they relate to auditory processing in subtypes of ADHD. Having this breadth of information will add to the ongoing line of research that has sought to implicate areas of the brain that are involved in the development of ADHD. Additionally, application of neuropsychological measures such as these, and those used in the current research, will shed light on functional aspects of the development of ADHD.

Due to the complexity of neuropsychological factors that are related to the development of ADHD, a study that utilizes MRI technology in addition to neuropsychological measures is warranted. Prior MRI research has indicated that the right frontal lobe is related to ADHD (Hynd et al,. 1990; Celune et al., 1986; Voeller et al., 1988; Schaughency & Hynd, 1989). In addition, research has implicated the role of the corpus callosum in ADHD (Hynd et al., 1991).

Although to date there are no published MRI studies that have investigated auditory processing in children with ADHD, past research that has applied measures of electrical activity in the brain provide positive results. Jonkman, Kemner, Verbaten, Koelega (1997) sought to determine if abnormal auditory selective attention is reflected in processing negativity of the event-related potential. The authors found abnormalities demonstrated by less modulation of cortical activity in children with ADHD.

Due to the growing knowledge base that highlights the complexity of the attentional system (Teeter & Semrud-Clikeman, 1994), it is imperative that research addresses ADHD as having an underlying systemic neurological basis. Thus, studies that investigate multiple areas of neuropsychological functioning, including auditory processing are warranted to further understand the continuum of attention impairment.

Future research that applies the current methodology but uses a different measure of auditory processing is warranted. This would help to clarify the role of auditory processing in ADHD assuming that this measure does not present similar problems as the SCAN. It would also clarify the nature of the relationship between auditory processing and auditory attention. It is possible that the auditory processing system of the brain and the attentional system are interconnected and that this contributes to difficulties in measurement.

Case by case analysis of data yielded information that is worthy of future inquiry. With a larger number of participants, the pattern that emerged in the group of “overlap” participants could be further investigated. This pattern may be an artifact of the current study. However, it may also represent a pattern that when analyzed provides clinically useful information regarding neuropsychological functioning in ADHD.

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